Beam Dynamics in Longitudinal Phase Space
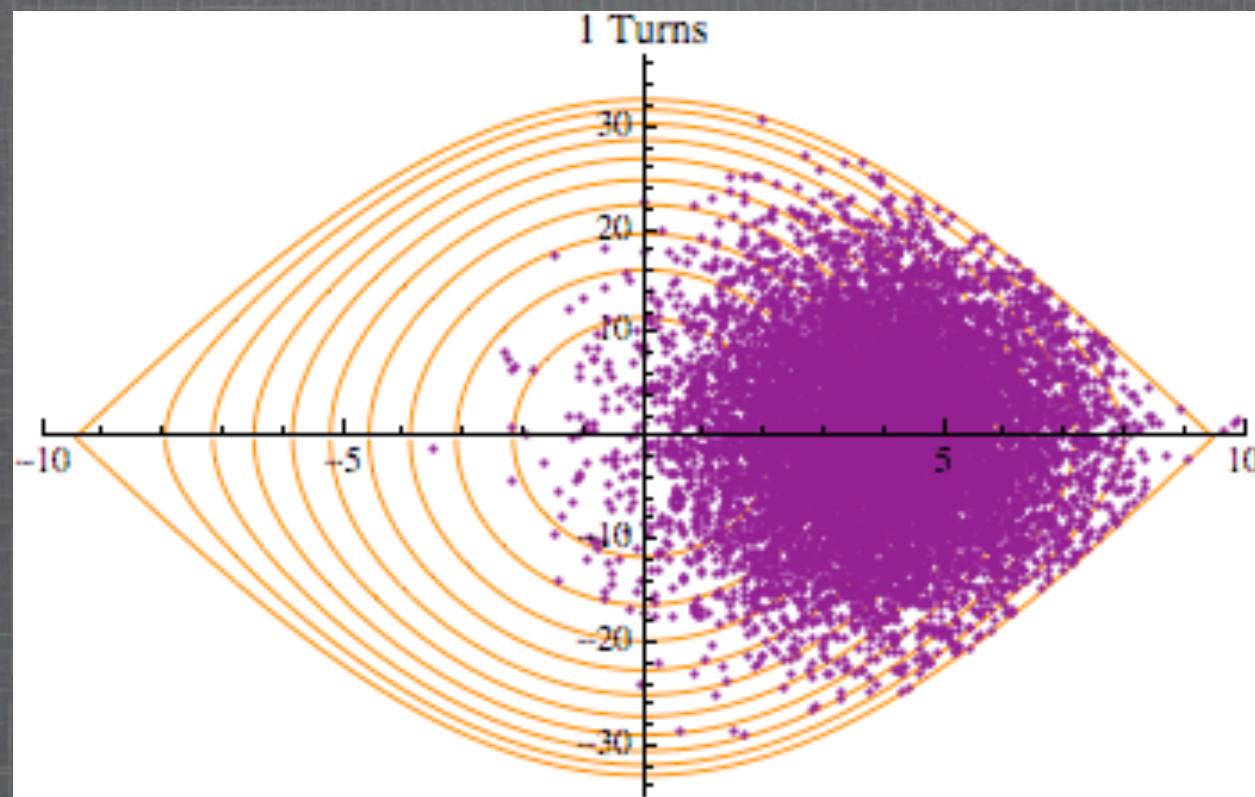
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Fermilab

Introduction

- Longitudinal Dynamics in Synchrotrons
  - What energy does the particle gain/lose, and how does its phase shift relative to the RF frequency

- Tomography
  - Method of reconstructing a two dimensional distribution from a sequence of one dimensional profiles taken at various angles, a CT scan is one example
  - Fermilab tomography program reconstructs the beam in longitudinal phase space using a series of projections from a WCM

- Studying Tomography without a Beam
  - Simulate and reconstruct the density in longitudinal phase space
    - First, for a well understood "matched" beam, then extended to the unmatched case

Fermilab's Main Injector

- 8 GeV to 120 GeV rapid cycling synchrotron
    - cycles in 1.33 seconds, after latest upgrade
    - 11 μs period
- Generates high intensity proton beams for various particle physics experiments
    - Latest focus is to produce high intensity neutrino beams
- Our goal: provide users with high quality beam
    - Understand beam dynamics in order to manipulate them
- Tomography goal: a real time reconstruction of the beam in longitudinal phase space (LPS)
    - LPS tomography first implemented at CERN c. 2000

Longitudinal Dynamics

- Non-Linear potential
  - Sinusoidal relationship between kinetic and potential energy, comparable to a pendulum

- Conservative System
  - For stationary buckets, particles move in contours of constant total energy governed by the Hamiltonian,
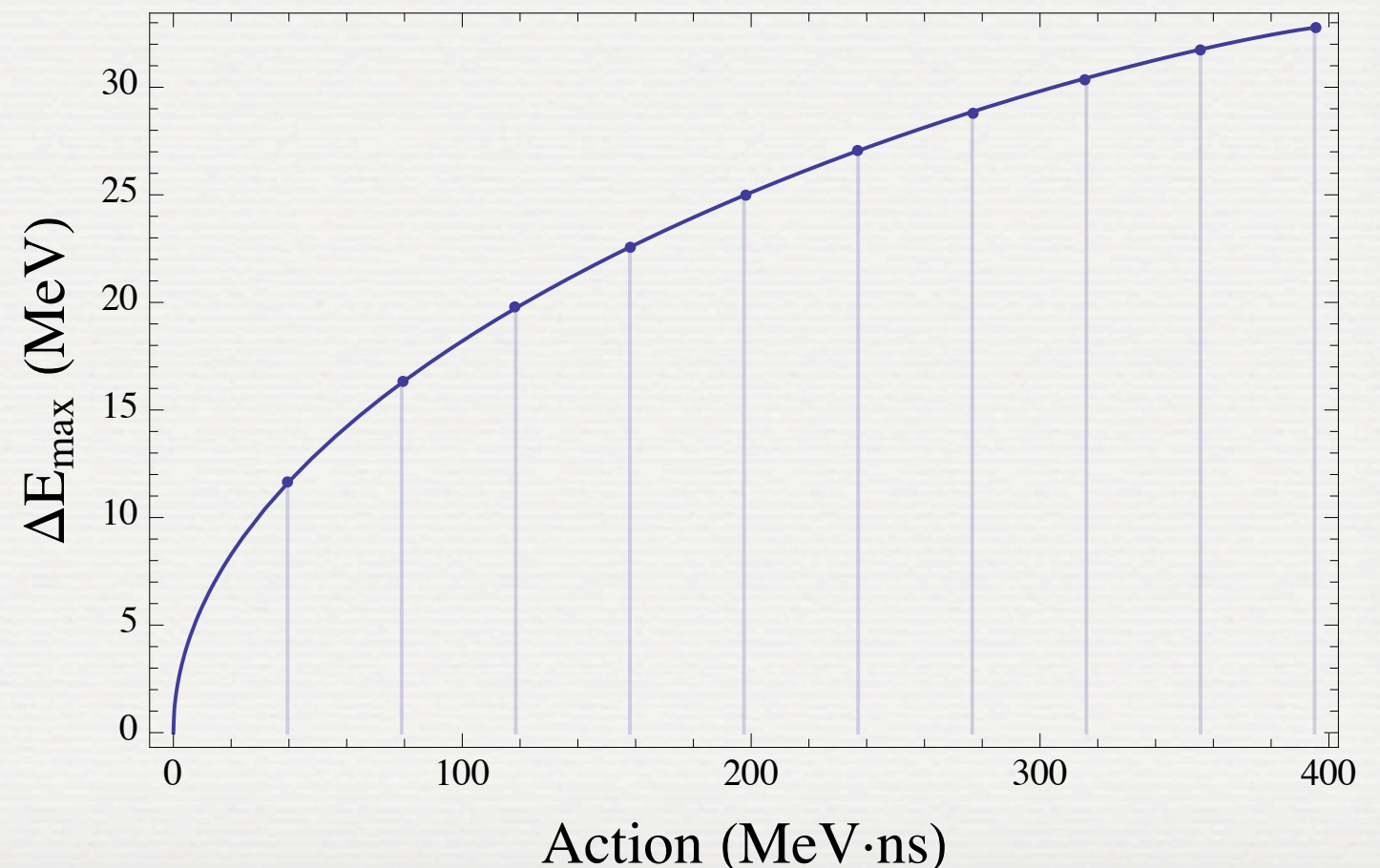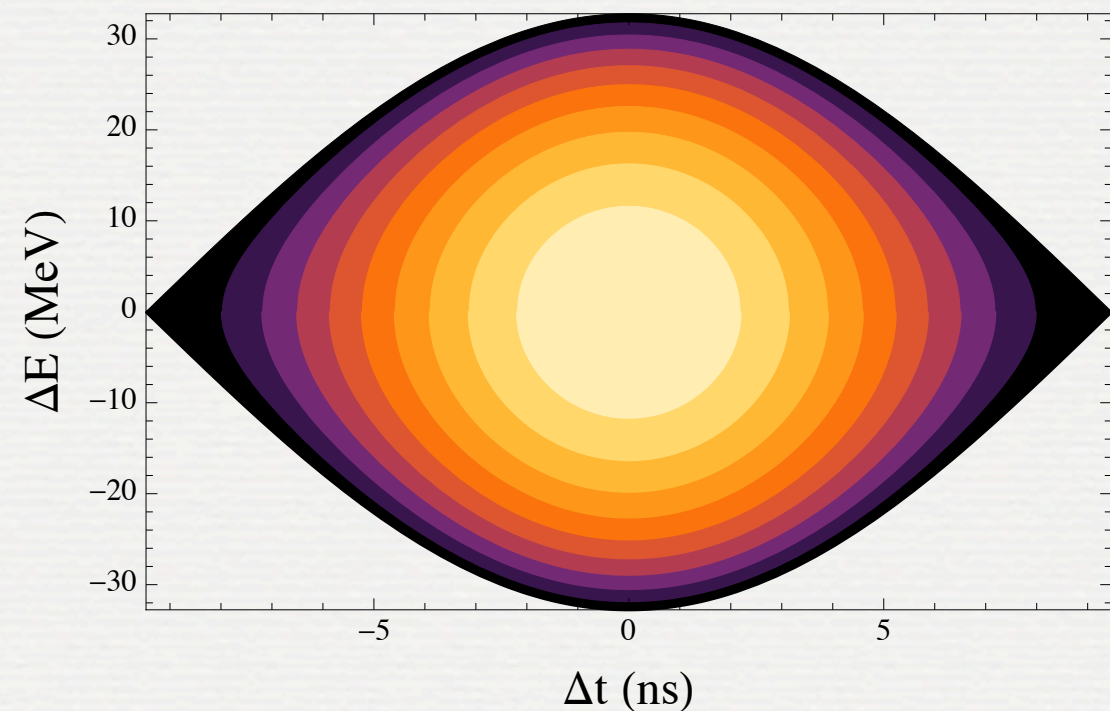
$$\Delta E^2 + \frac{E_s \, eV \, \beta^2}{\eta \, \pi \, h} \left(Cos \, \phi + \phi \, Sin \, \phi_s \right) = \mathcal{H}$$

  - Where the phase can also be expressed as Δt to RF phase

- Matched Bunch vs Unmatched
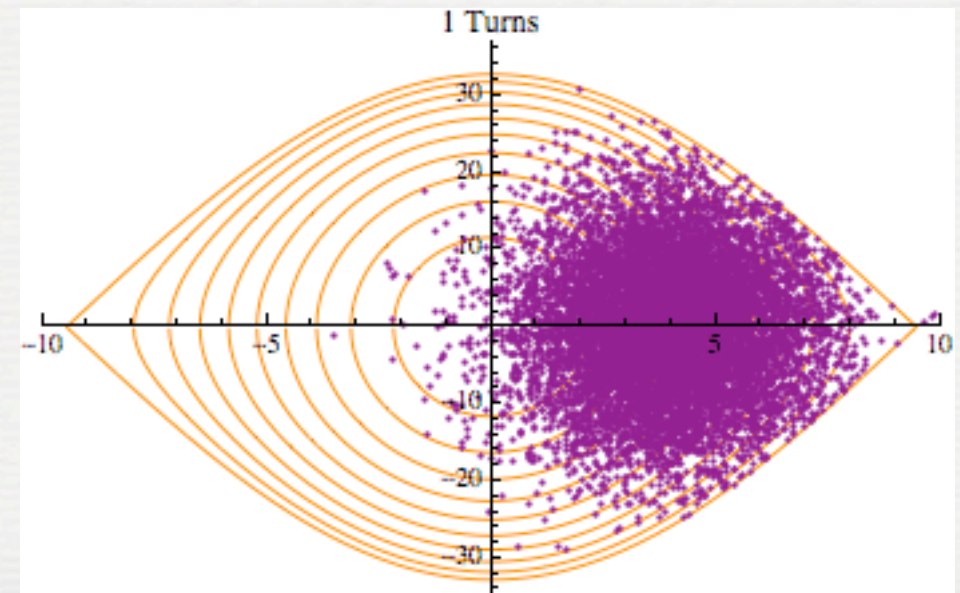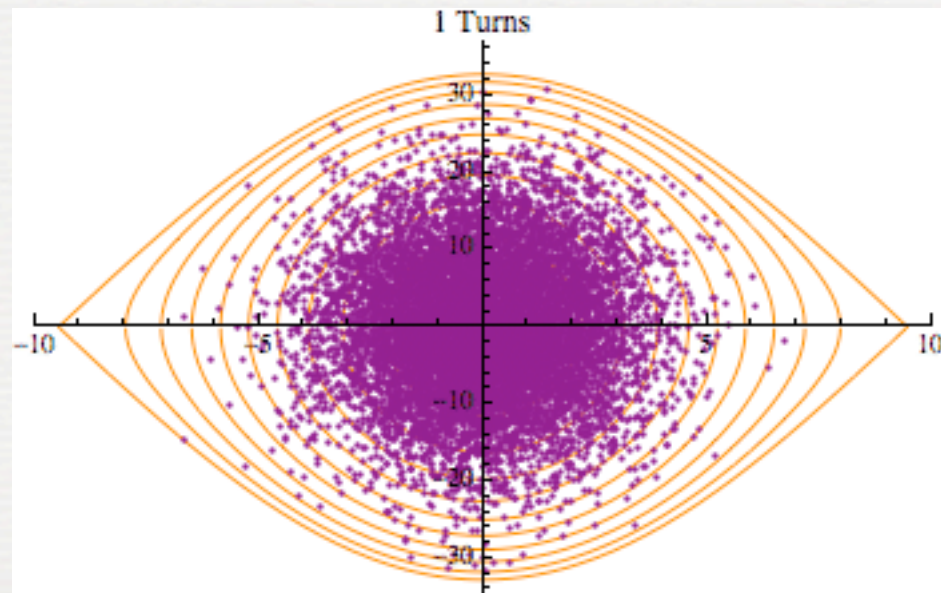
Reconstructing a Matched Beam

- Start with a series of contours with identical action (MeV•ns) increases

- Hamiltonians of such contours found via interpolation of arbitrary data
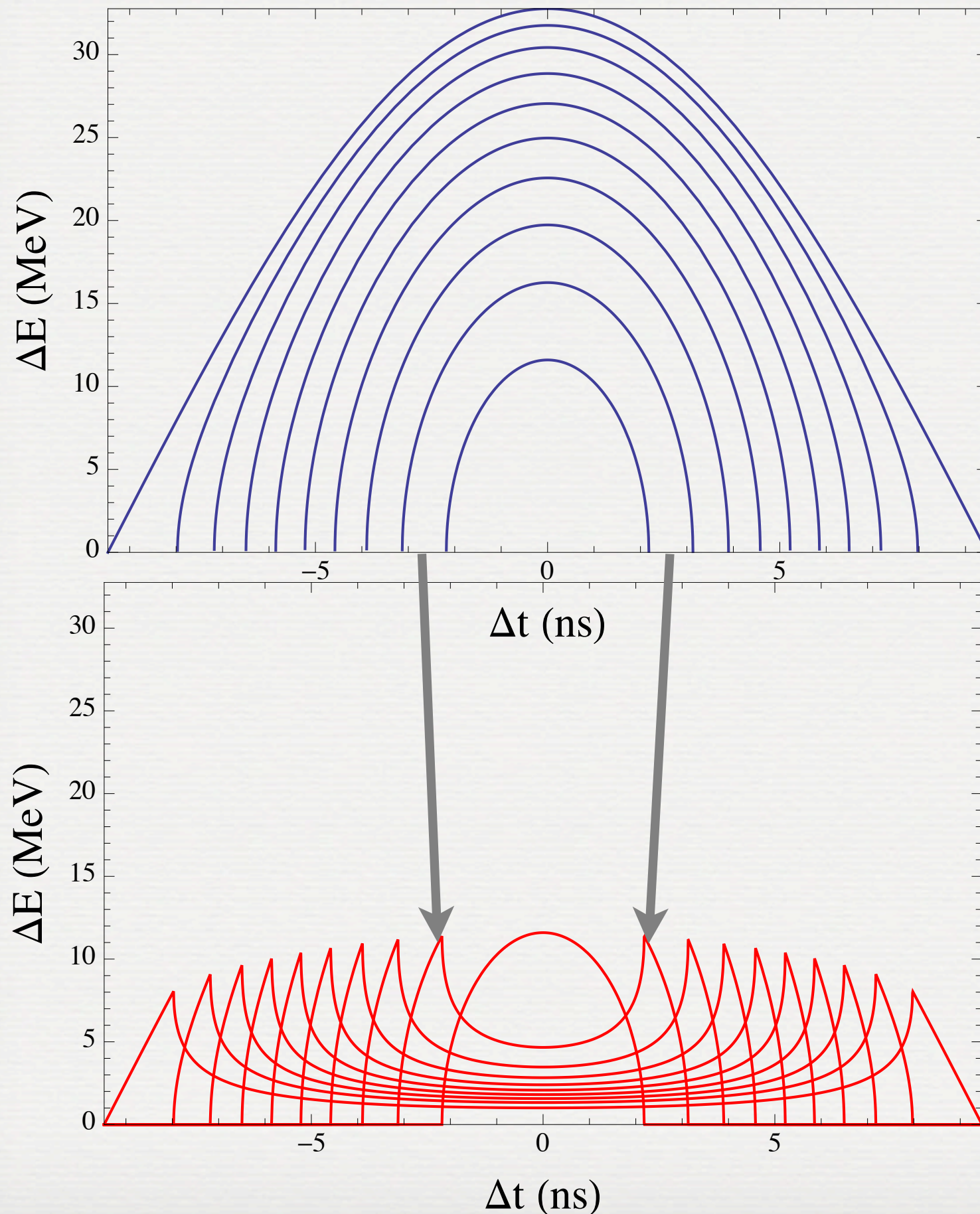
- Area <u>between</u> contours is projected onto the time axis

- These time dependent "sombrero" functions are then used to reconstruct the beam
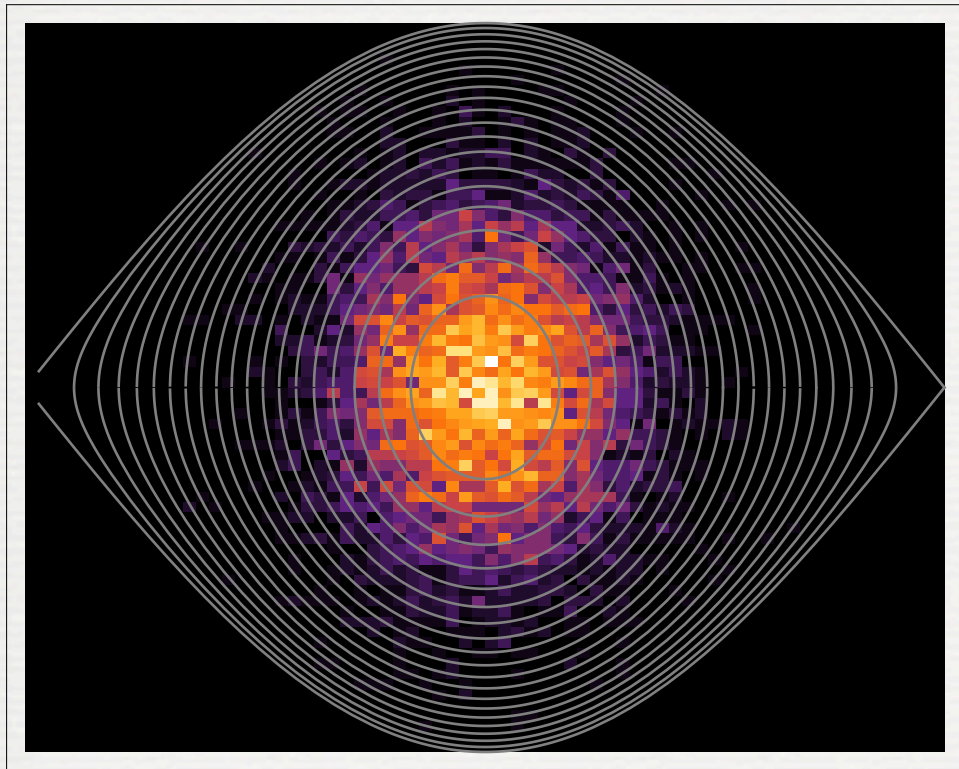
- 2-D gaussian particle distribution is projected down to a 1-D time profile

- A linear combination of the sombrero functions is fit to the profile

  - coefficients are restricted to positive values

- Normalized sombrero coefficients are compared to actual percentage of particles in the corresponding actions
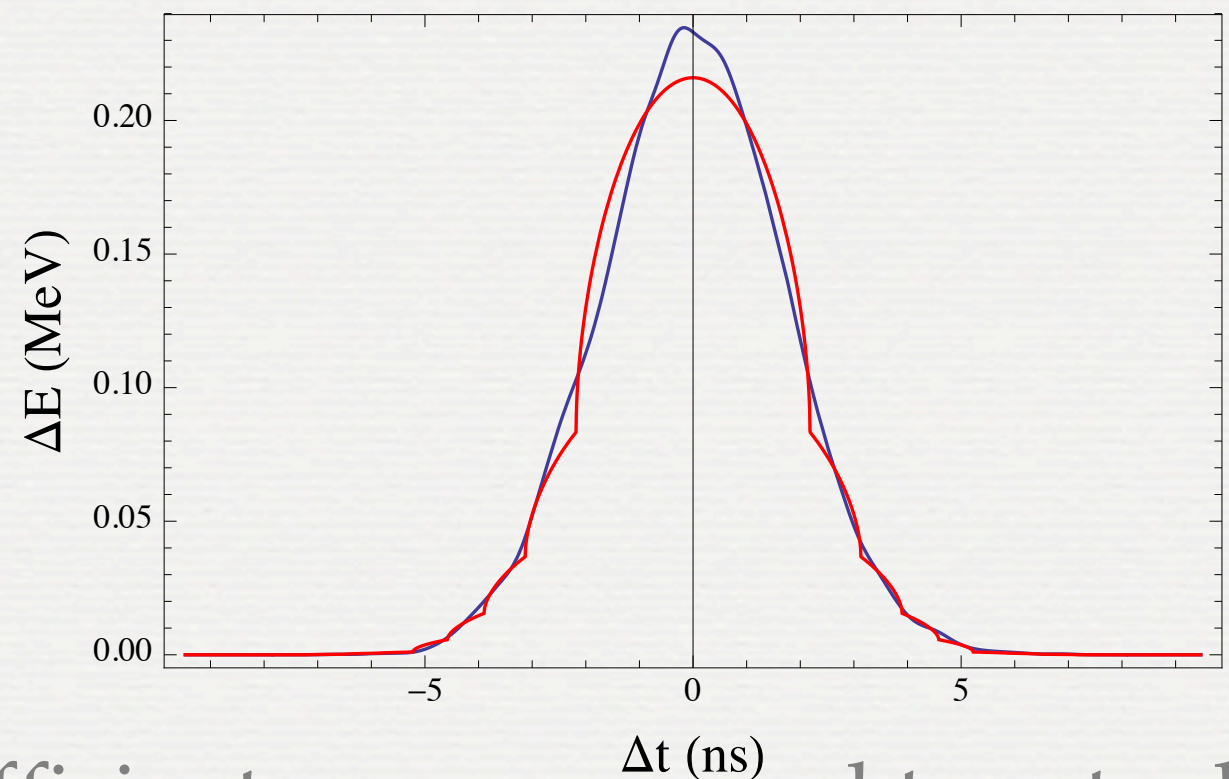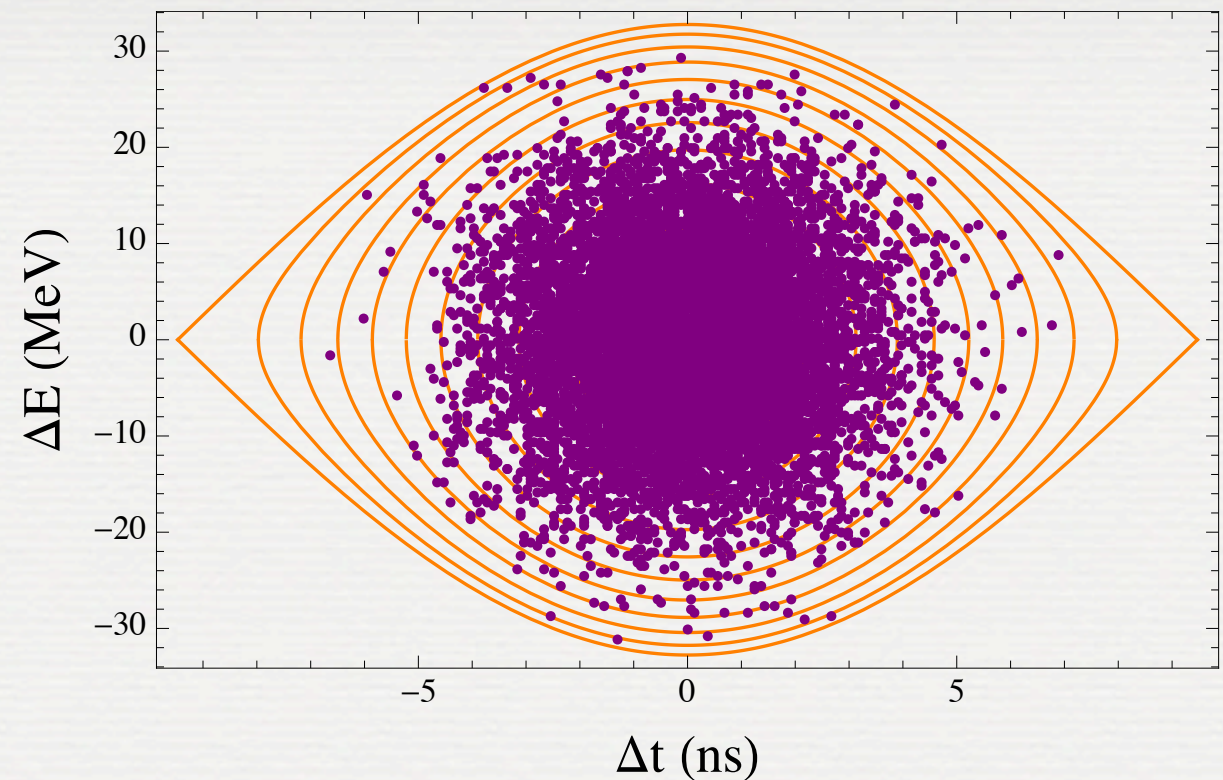
Results of Matched Beam Reconstruction
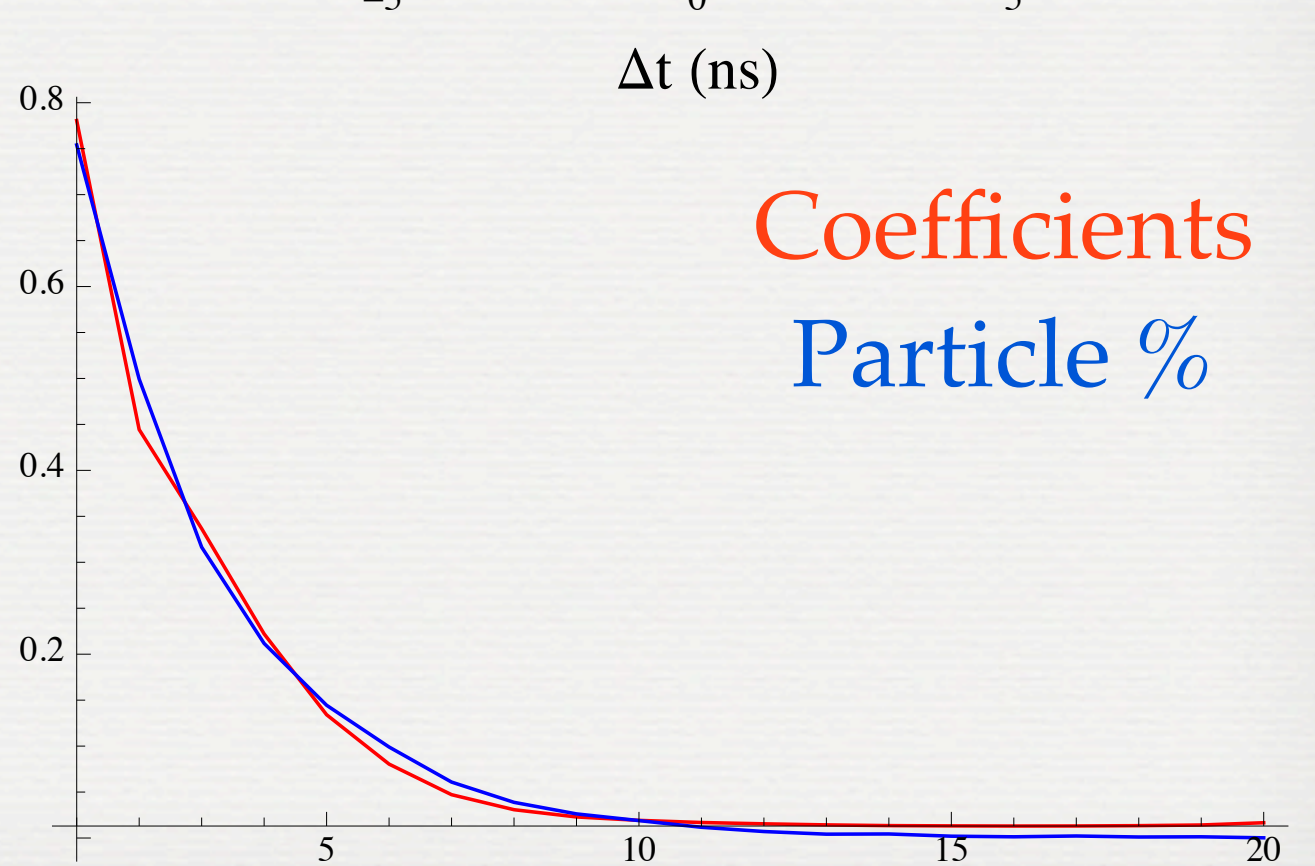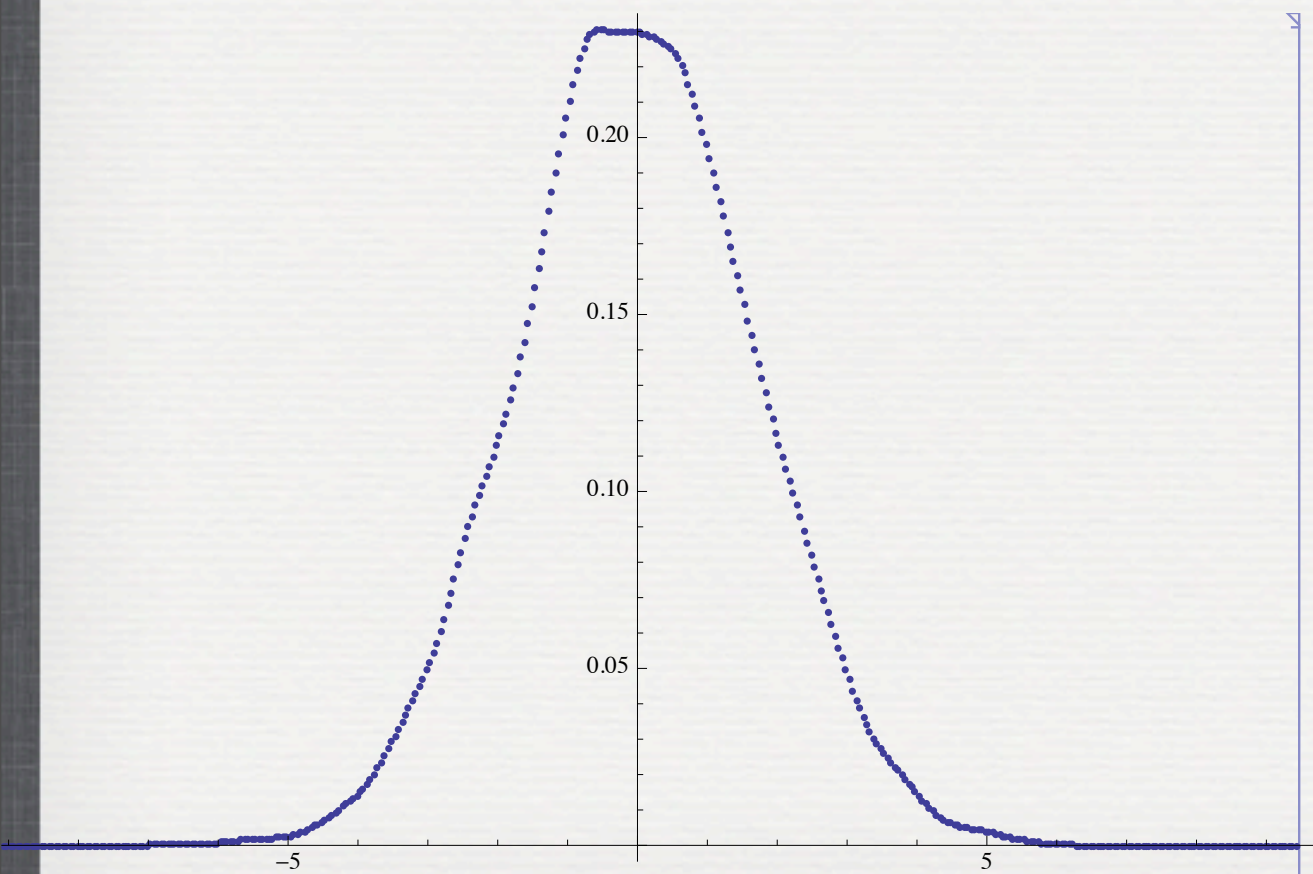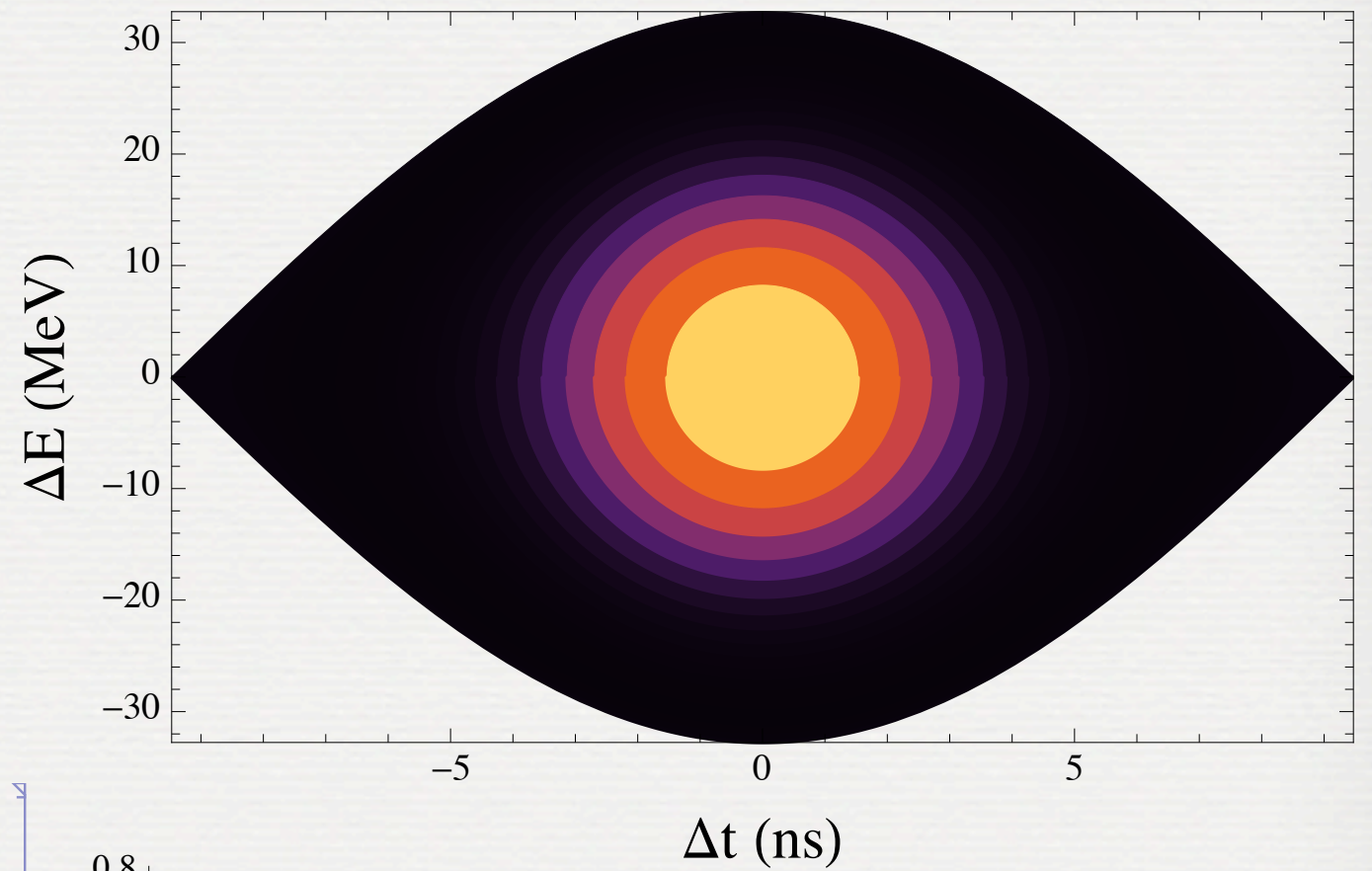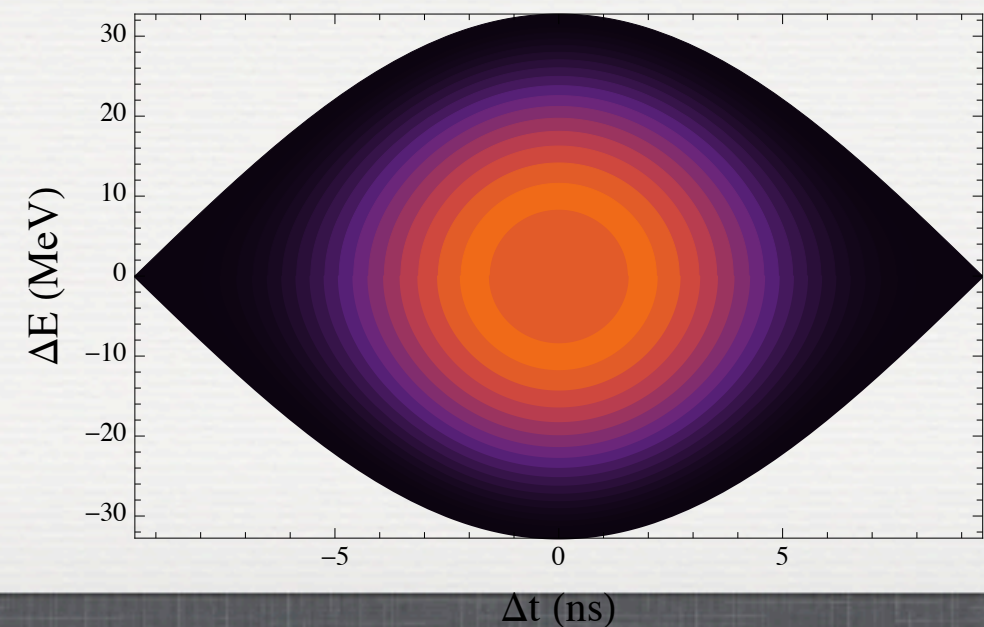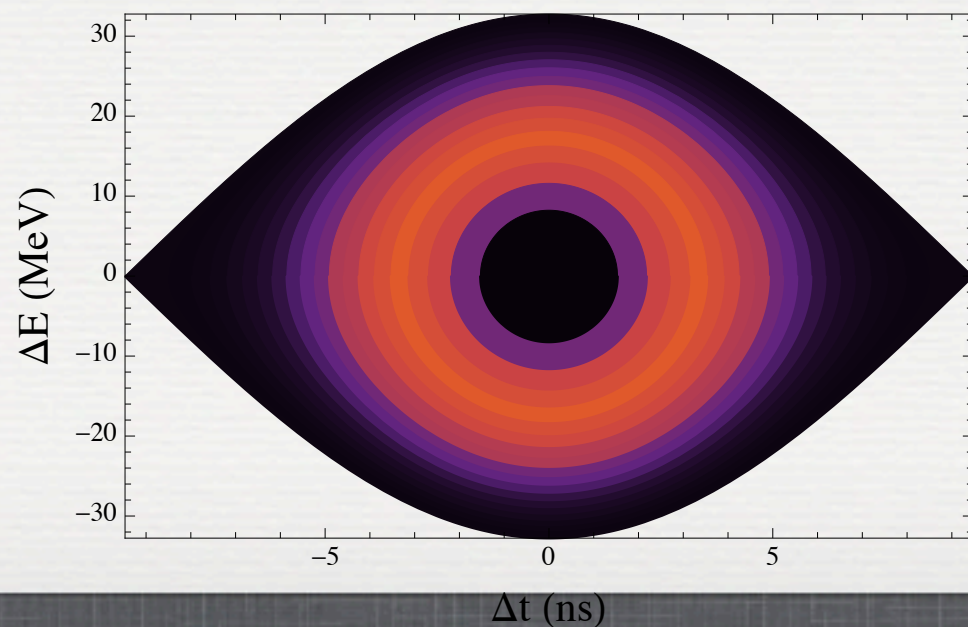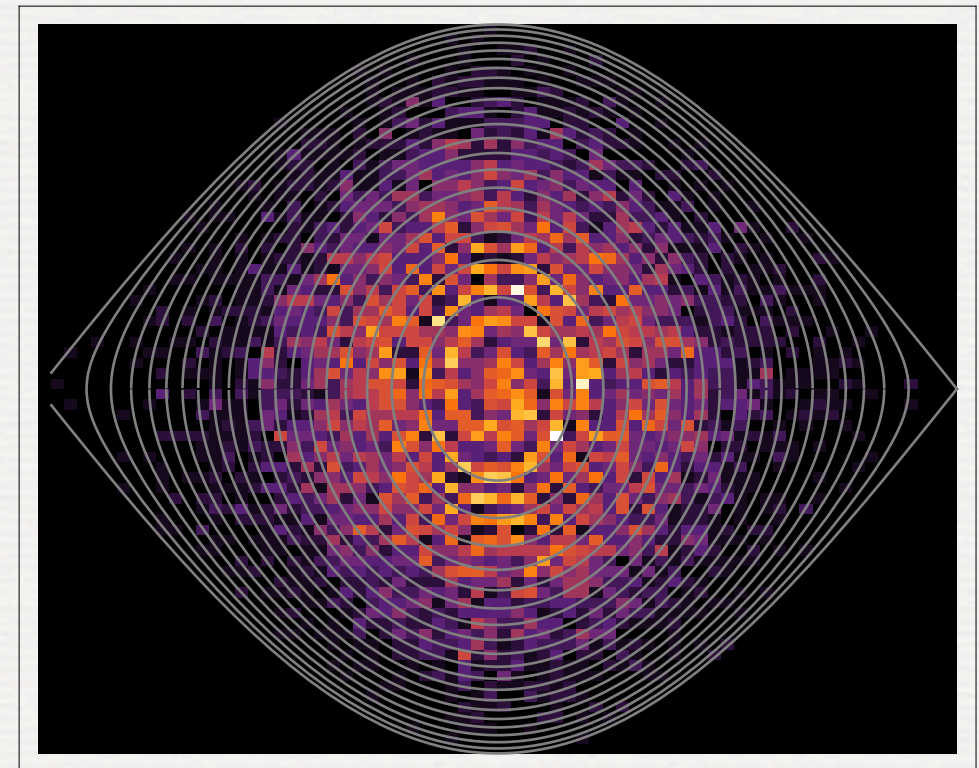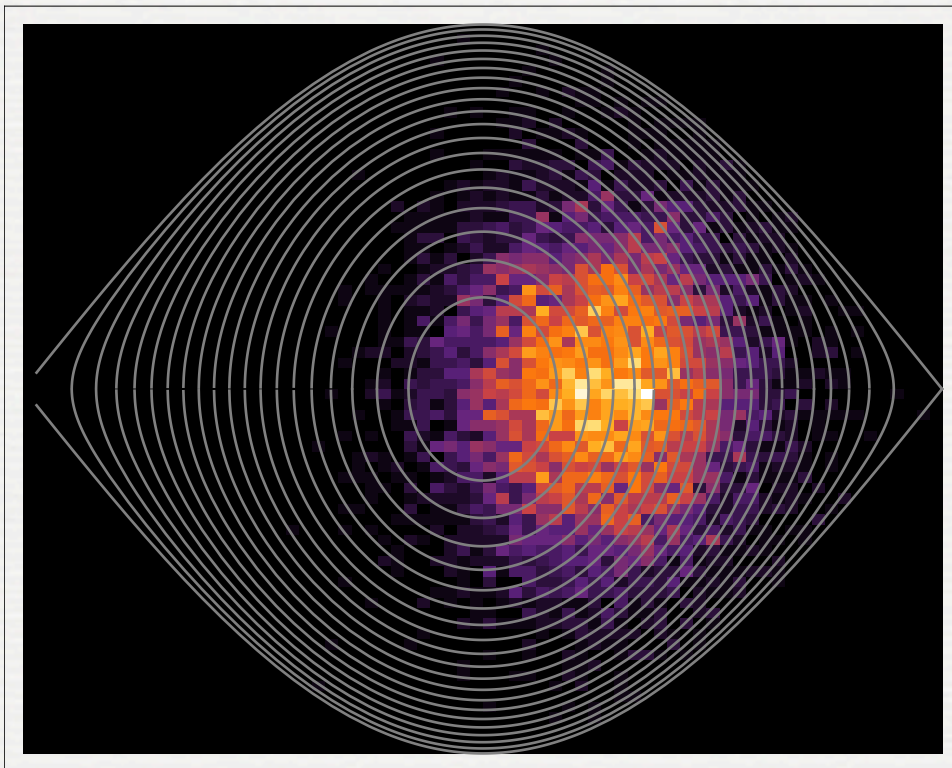
Reconstructing an Unmatched Bunch

- Test this single profile reconstruction method on an off-axis beam
- Track the same beam to equilibrium and then retest
- Compare the initial sombrero fits and coefficients to the equilibrium fits and coefficients
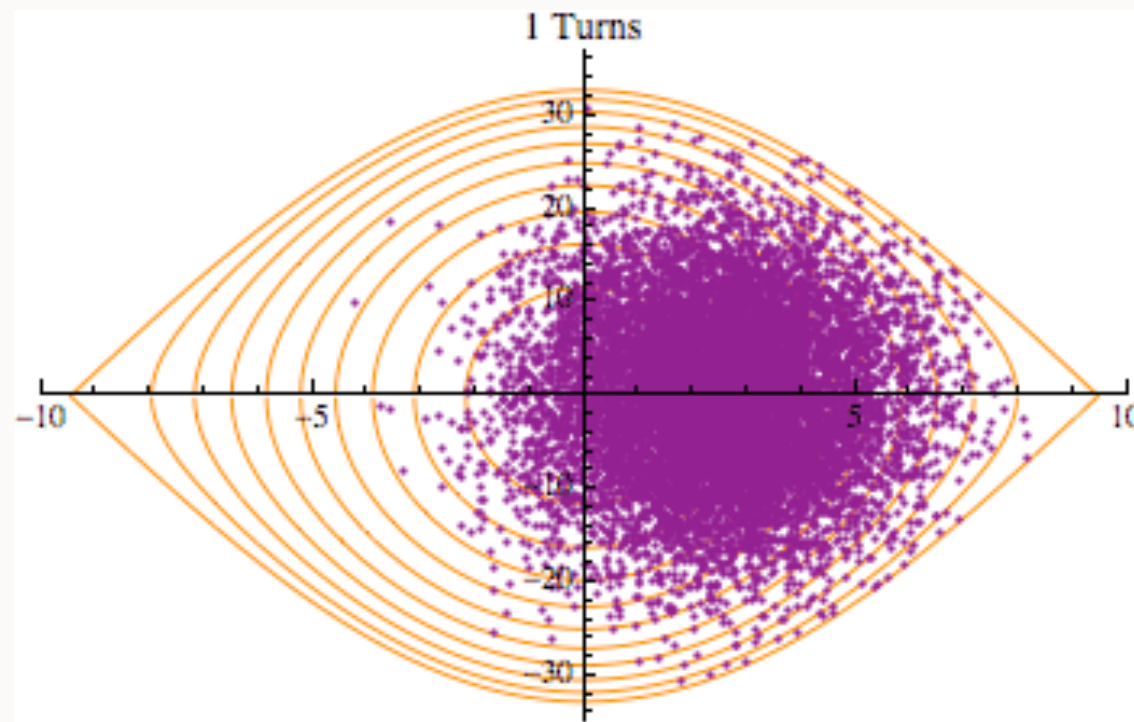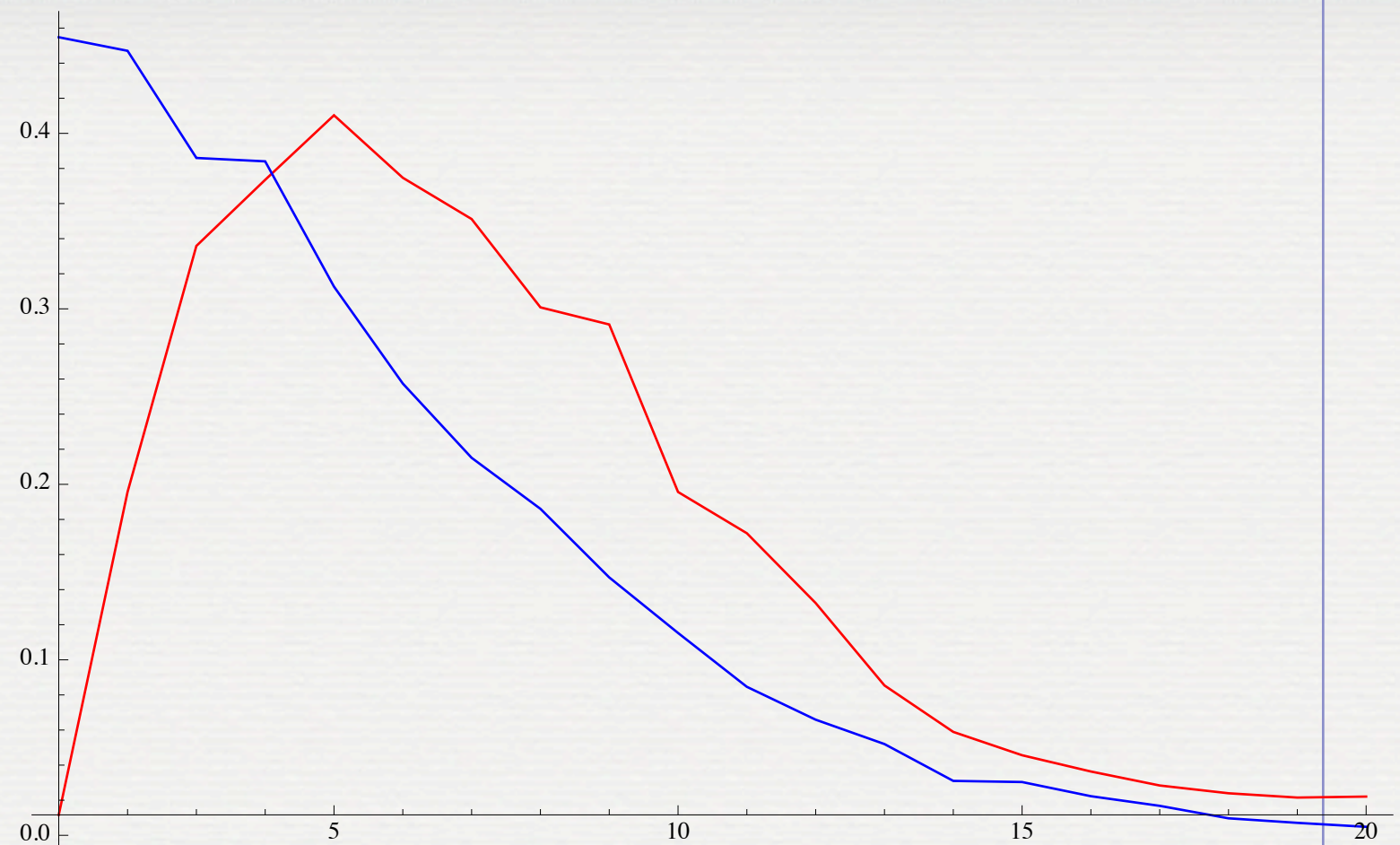
Initial distribution of unmatched bunch
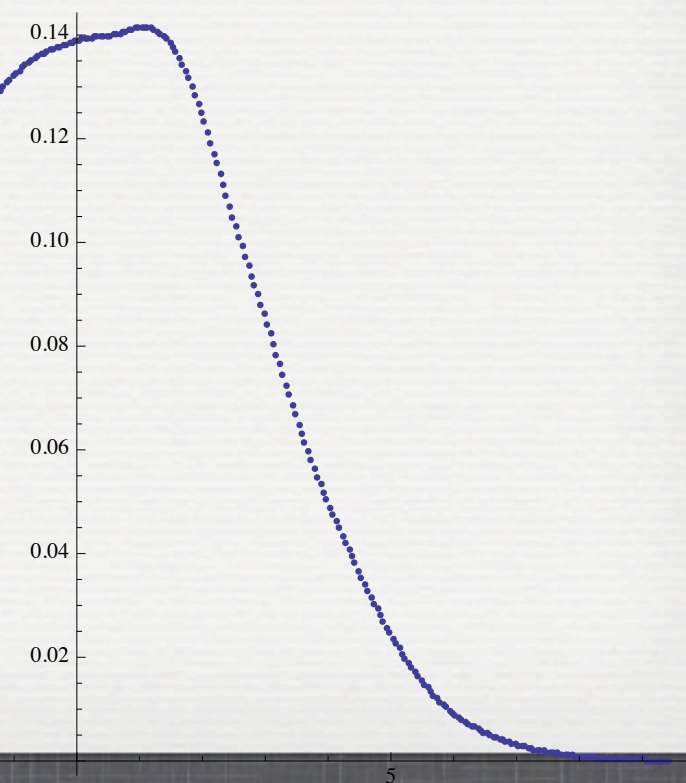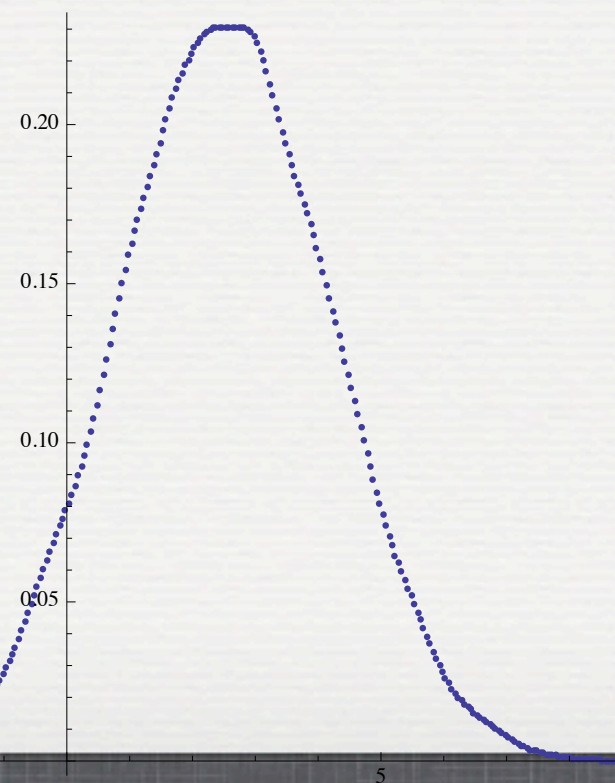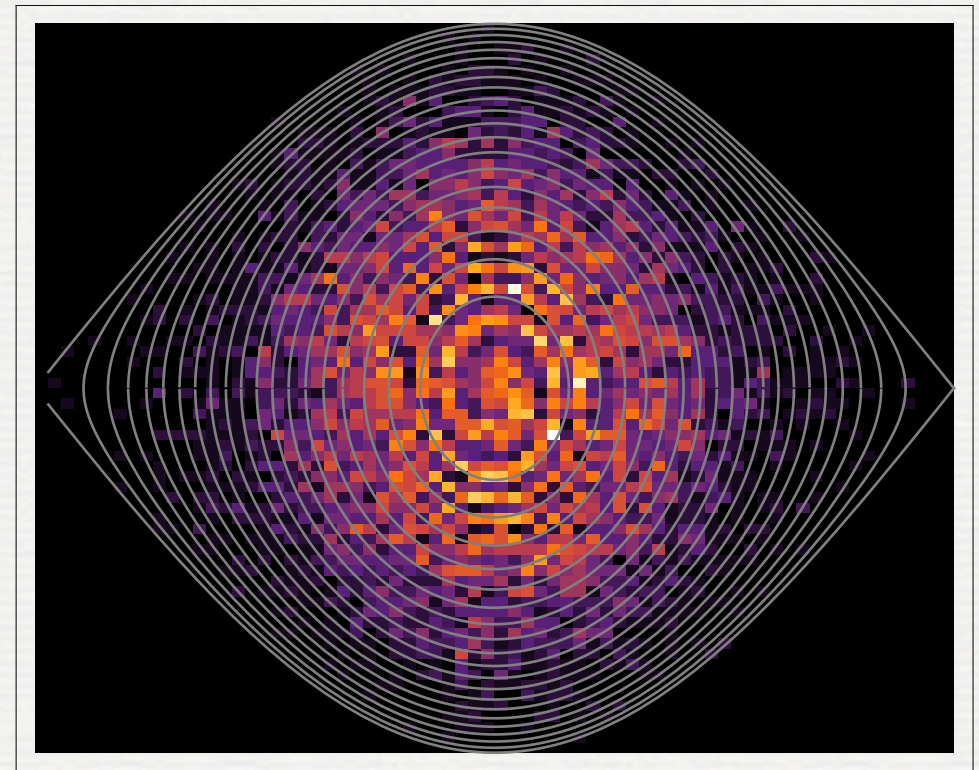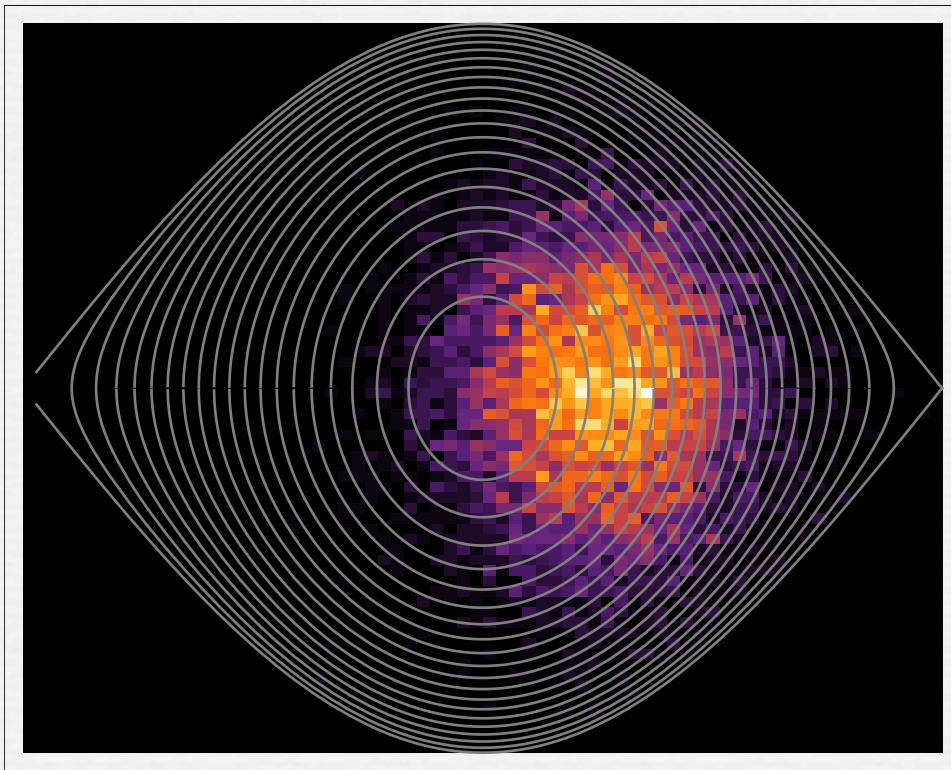
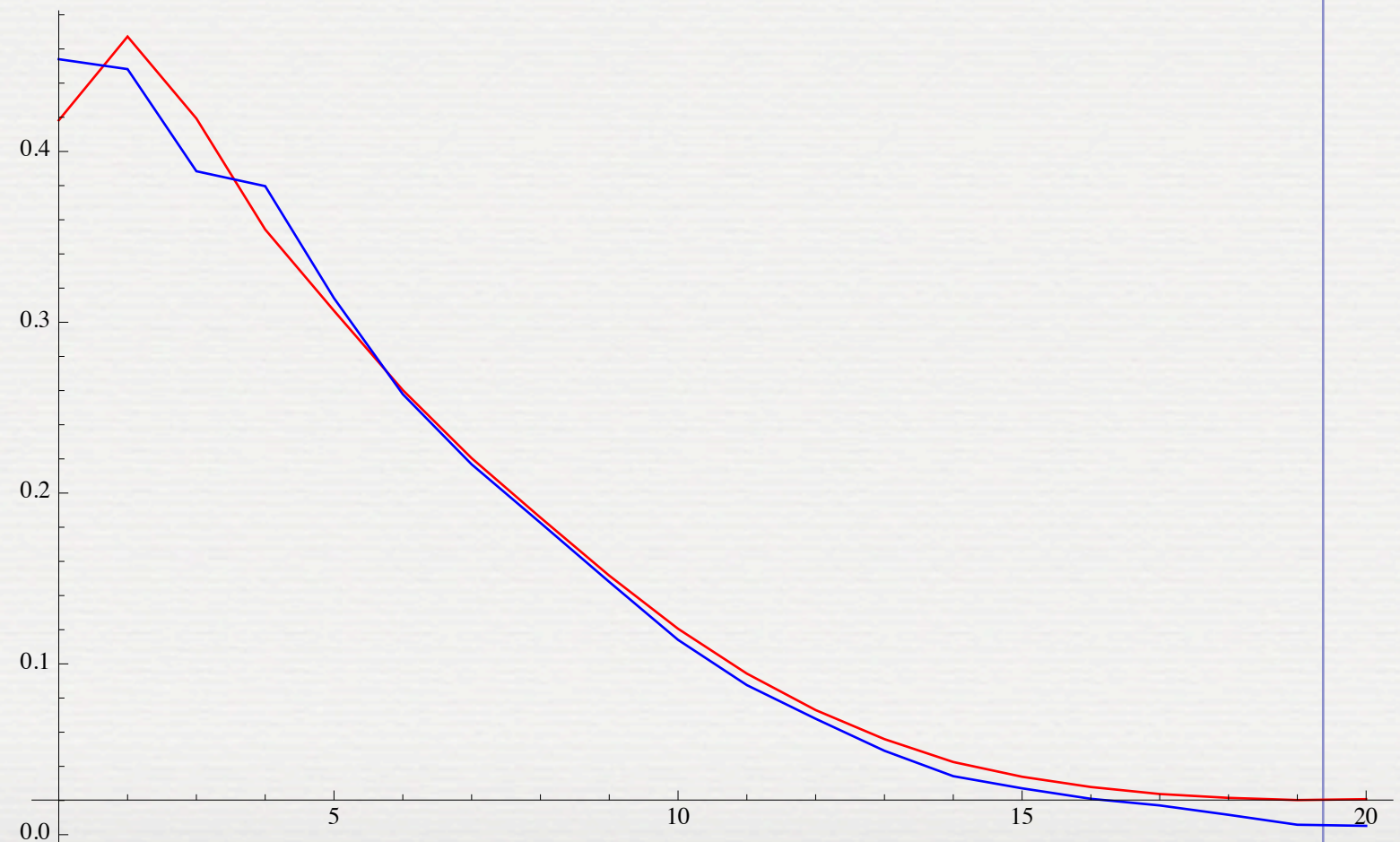- **Distribution of unmatched bunch after being tracked to equilibrium**

Fit Before
Tracking

Coefficients
Particle %

Fit After
Tracking

Conclusion

- Results are more or less what we expected

  - Single profile reconstructions are possible with beams in equilibrium

  - Cannot show reconstructions leading up to equilibrium

- From here we could

  - Optimize the code

  - Test method on actual Beam

Acknowledgements

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